

Maternal Dietary Intake of Total Fat, Saturated Fat, and Added Sugar Is Associated with Infant Adiposity and Weight Status at 6 mo of Age

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ABSTRACT

Background: Whether current dietary guidelines are appropriate for pregnancy and lactation has not been well studied. Many women of reproductive age are not meeting recommendations for dietary components such as fat, added sugar, and fiber.

Objectives: To assess associations between maternal dietary components during pregnancy and lactation and infant growth and adiposity at 6 mo of age.

Methods: Mother–infant dyads ($n = 349$) from the prospective, observational Mothers and Infants Linked for Healthy Growth study were included (100% fully breastfed for 1 mo; 75% to 6 mo). Daily intake of fat, fiber, and added sugar was obtained using the National Cancer Institute Diet History Questionnaire II during the third trimester of pregnancy and at 1 and 3 mo postpartum. Furthermore, intakes were categorized as meeting/exceeding 2015–2020 Dietary Guidelines for Americans. Multiple linear regression models adjusted for numerous potential confounders tested relations between dietary components and infant adiposity (via DXA) and growth parameters. Regression coefficients (β) for continuous variables were expressed per SD to allow for comparison of effect sizes.

Results: Maternal intake of total fat and saturated fat was positively associated with infant percent body fat (%BF) (β : 0.84 per SD, $P = 0.04$; β : 0.96 per SD, $P = 0.01$, respectively). Added sugar intake was positively associated with infant weight-for-length z score (β : 0.16 per SD, $P = 0.02$), and excessive added sugar intake was positively associated with %BF at 6 mo (β : 0.75 per SD, $P = 0.05$).

Conclusions: In a predominantly fully breastfeeding cohort of women, maternal intake of fat and added sugar during pregnancy and lactation were associated with small increases in infant adiposity and relative weight at 6 mo. Additional research is needed to determine if these relations persist later in infancy and if such elevations in adiposity are important for long-term obesity risk. *J Nutr* 2021;151:2353–2360.

Keywords: infant, body composition, maternal diet, Nutrition, human milk

Introduction

Adequate nutritional intake during pregnancy and lactation is critical to fetal and infant growth (1–6). In addition, lack of maternal adherence to dietary recommendations may lead to altered growth in early infancy, a period that may have later implications for conditions such as obesity (7), diabetes (8), and cardiovascular disease (9). The most recent pregnancy nutrition guidance was published over 30 y ago [Institute of Medicine (IOM)], and updated guidelines for nutrition during this critical period are being developed (10). Given the marked changes in maternal obesity and dietary intake in recent decades, it is important to update our knowledge with assessment of the

relations between maternal diet and infant nutritional status among contemporary women.

The 2015–2020 Dietary Guidelines for Americans (DGA) recommend that fat comprise $\leq 35\%$ total calories and saturated fat $< 10\%$ total calories per day (11). From 2013 to 2016, pregnant and lactating women between 20 and 44 y old consumed 35% and 37% of their total calories as fat, respectively, with 12% from saturated fat (12). Over the same time period, these women consumed 9 g of fiber/1000 kcal, falling short of the 14 g/1000 kcal recommended by the DGA (11, 12). The 2003–2012 NHANES found that pregnant women between the ages of 20 and 39 y consumed 14.8% and nonpregnant women consumed 15.9% of their total daily

calories from added sugar (sugars or syrups added to food or beverages during processing) (12), contrasting the 2015–2020 DGA recommendations for limiting added sugar to <10% total calories (13).

A number of existing studies have examined maternal diet quality (14, 15), dietary patterns (16), and some individual dietary components, including protein, in relation with infant growth and adiposity at birth (1, 2). However, few studies have assessed the relation between maternal intake of dietary fat, added sugar, or fiber with growth and adiposity during infancy, despite the frequent lack of instruction on and/or adherence to guidelines for these dietary components (17–19). Furthermore, it is known that breastfed infants tend to have greater adiposity early on than formula-fed infants (20, 21) and that breastfeeding is more common among women of higher socioeconomic status who may be able to afford higher-quality diets (22, 23). Therefore, it is important that the assessment of maternal diet in relation to infant growth and body composition controls, as far as possible, for the duration and intensity of breastfeeding (20).

To address this gap, we examined the contributions of variation in specific maternal dietary components (total fat, saturated fat, unsaturated fat, fiber, and added sugar) to growth and adiposity outcomes in predominantly fully breastfed infants. We hypothesized that maternal intake of fat and added sugar would be positively associated, while fiber intake would be inversely associated with infant adiposity at 6 mo of age. We also hypothesized that fat and added sugar would be associated with greater infant weight-for-length *z* scores (WLZ) at 6 mo of age and greater change in weight-for-age *z* score (Δ WAZ) from 1–6 mo of age, whereas intake of fiber would be associated with decreased WLZ and Δ WAZ. Finally, we examined overall infant size (length) to help interpret and contextualize the findings on relative weight and adiposity.

Methods

Study population

Data from mother–infant dyads enrolled in the Mothers and Infants Linked for Healthy Growth (MILk) study, an ongoing prospective cohort study in Minneapolis, Minnesota, and Oklahoma City, Oklahoma, were included in these analyses (24). Maternal inclusion criteria were 21–45 y of age at delivery, prepregnancy BMI (in kg/m²)

of 18.5–40.0, healthy singleton pregnancy (<3-d hospitalization for vaginal deliveries and <5-d hospitalization for caesarian deliveries), delivery of term infant with birthweight between 2500 and 4500 g, and reported intention to breastfeed for a minimum of 3 mo. Women were excluded if they consumed tobacco or >1 alcoholic drink weekly during pregnancy/lactation, had a history of type 1 or type 2 diabetes or had gestational diabetes, were unable to speak or understand English, or if infants had a congenital illness known to affect feeding and/or growth. The MILk study enrolled 370 mother–infant dyads, and 349 were retained in the final analytic sample after exclusion of dyads with incomplete data.

The institutional review boards at the University of Minnesota, HealthPartners Institute, and the University of Oklahoma Health Sciences Center approved MILk study protocols. Study participants provided written informed consent and were compensated after each study visit was completed.

Maternal characteristics and dietary components

Clinical characteristics of maternal participants were collected from the electronic health records, including parity (0, ≥ 1), mode of delivery (vaginal delivery or cesarean section), first recorded maternal weight and height in the medical record within 6 wk from conception (dated using last menstrual period), prepregnancy BMI, gestational weight gain (GWG; body weight at admission for delivery minus the first recorded maternal weight), and maternal age (years). Maternal race (white, other) and education level (high school/GED/associate's degree; bachelor's degree; graduate degree) was also collected.

Dietary information was obtained using an FFQ [the National Cancer Institute's Diet History Questionnaire II (DHQ II)] during the third trimester of pregnancy and at 1 and 3 mo postpartum. This version used prompted, nonquantitative estimates of food intake frequencies for the month prior to each time point (25). Nutrient intake estimates from each DHQ II administration were moderately to strongly correlated ($r \geq 0.55$, $P < 0.0001$ for total calories, fat, saturated fat, unsaturated fat, and fiber and $r \geq 0.42$, $P < 0.0001$ for added sugars) and not significantly different in mean value (t test $P > 0.10$ for all) among each of these closely spaced time points, except for unsaturated fat, which was approximately 3 g lower in pregnancy than lactation ($P = 0.04$). Therefore, mean dietary intake data were used to provide an estimate of the daily maternal consumption of total fat, saturated fat, unsaturated fat, fiber, and added sugars (grams per day) across the period from late pregnancy to 3 mo postpartum. Total fat intake was categorized as meeting or exceeding the 2015–2020 DGA recommendations for $\leq 35\%$ total calories (26), and saturated fat intake was categorized as meeting or exceeding recommendations for <10% total caloric intake (11). Fiber intake was categorized as meeting/exceeding or not meeting DGA recommendations for ≥ 14 g/1000 kcal (11), and added sugar intake was categorized as meeting or exceeding DGA recommendations for <10% total daily caloric intake (11). The mean Healthy Eating Index 2015 score for dietary intake was calculated to assess the overall quality of maternal dietary intake. A higher total score (out of 100) represents greater adherence to the 2015–2020 DGA (27). Supplementation of fiber was not assessed in the DHQ II.

Infant anthropometrics and body composition

At 6 mo of age, infants had anthropometric measurements (weight and length) taken as described previously (28). Standardized *z* scores for weight, length, and weight for length were obtained using the WHO growth charts (29). Infant adiposity [percent body fat (%BF)] was assessed via DXA (Lunar iDXAv11–30.062 scanner; analysis via enCore 2007 software; GE) in infants at the 6-mo study visit as described previously (30).

Breastfeeding status

Breastfeeding status was assessed during study visits when infants were 1, 3, and 6 mo of age and was classified as fully breastfeeding, mixed feeding, or fully formula feeding based on maternal self-report. Fully breastfeeding infants received <24 oz (720 mL) of formula since birth or

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Supplemental Tables 1–5 are available from the “Supplementary Data” link in the online posting of the article and from the same link in the online table of contents at <https://academic.oup.com/jn>.

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Abbreviations used: DGA, Dietary Guidelines for Americans; DHQ II, Diet History Questionnaire II; GWG, gestational weight gain; IOM, Institute of Medicine; LAZ, length-for-age *z* score; MILk, Mothers and Infants Linked for Healthy Growth; SDS, SD score; WLZ, weight-for-length *z* score, %BF, percent body fat; Δ WAZ, change in weight-for-age *z* score from 1 to 6 mo.

their last study visit and only breast milk for 2 wk prior to the study visit. Infants receiving mixed feeding consumed >24 oz (720 mL) of formula for each time period in addition to some breast milk, and infants fully formula feeding received only formula for each time period.

Statistical analyses

The MILk study enrolled 370 mother–infant dyads. Of these, a total of 278 participants had complete sets of all maternal dietary data and infant growth data available for analysis, whereas the remainder (20%) had ≥ 1 of these variables missing. The percentage of missing values for individual variables ranged from 0% to 11%. Thus, multiple imputation by fully conditional specification was conducted for analysis. The data were first assessed for influential outliers; data were only retained in the model if they did not significantly change the associations between predictor and outcome variables. A total of 40 data sets were then imputed using predictive mean matching before pooling for analysis. Data were assumed to be missing at random.

Demographic and clinical characteristics of the mother–infant dyads were evaluated as raw mean \pm SE for continuous variables or frequency and percentage for categorical variables. Pearson correlations were calculated for maternal intake of dietary components during pregnancy, 1 mo postpartum, and 3 mo postpartum.

Multiple linear regression analyses tested the relation between mean maternal intake of dietary components as continuous variables (fat, saturated fat, unsaturated fat, added sugar, and fiber) or categorical variables (met or exceeded recommendations for fat and added sugar; fiber not examined due to small percentage of women meeting recommendations) and infant %BF and growth parameters, including Δ WAZ from 1 to 6 mo, length-for-age z score at 6 mo (LAZ), and weight-for-length z score at 6 mo (WLZ). Models were adjusted for potential confounders, including study center (Minnesota or Oklahoma) and maternal characteristics of age (years), prepregnancy BMI, GWG (below/within or exceeding IOM guidelines) (31), race (white, other), household income (<\$60,000, \$60,000–\$90,000, >\$90,000), education (high school/GED/associate's degree, bachelor's degree, graduate degree), parity, delivery mode (vaginal, cesarean section), duration of full breastfeeding (1, 3, or 6 mo), and mean daily calorie intake. Models were also adjusted for infant gestational age (weeks) and sex (male, female). Estimates were expressed per SD of the independent variables to allow for comparison of effect sizes.

To contextualize the findings, we also compared the effect sizes for dietary components that had the greatest effects on infant growth and adiposity in our analysis to those for duration of full breastfeeding (1, 3, or 6 mo), as it is known to have a strong influence on infant adiposity. We also assessed whether the initiation of complementary foods (any of fruit, vegetables, infant cereal, bread/crackers/rice/breakfast cereals/teething biscuits, or other foods) in addition to breast milk or formula affected the relation between maternal dietary intake and infant growth outcomes. We also tested associations of infant growth and adiposity with the 3 main diet variables (fat, fiber, and added sugar) simultaneously in the same adjusted models so that the independent effects of each could be determined. Finally, in a sensitivity analysis to determine if full breastfeeding affected the relation between maternal dietary components and infant growth and body composition, adjusted models were rerun in infants who were fully breastfed to 6 mo.

SAS Enterprise Guide, version 7.15 (SAS Institute) was used to conduct statistical analyses.

Results

Participant demographic characteristics

Demographic characteristics of mother–infant dyads are presented in Table 1. Most mothers were non-Hispanic white, had incomes >200% of poverty (70% with >\$60,000 income yearly), and were highly educated (77% achieved a bachelor's degree or higher). Most women were multiparous and delivered

TABLE 1 Demographic, pregnancy, and birth characteristics of mother–infant dyads ($n = 349$)¹

Participant characteristic	Value
Study site	
Minnesota	234 (67)
Oklahoma	115 (33)
Age, y	30.8 \pm 0.22
Race	
White	299 (86)
Other	50 (14)
Education	
High school/GED/associate's degree	80 (23)
Bachelor's degree	143 (41)
Graduate degree	126 (36)
Household income	
<\$60,000	107 (31)
\$60,000–\$90,000	87 (25)
>\$90,000	155 (44)
Parity	
0	148 (42)
≥ 1	201 (58)
Prepregnancy BMI, kg/m ²	26.1 \pm 0.25
Prepregnancy BMI <25	161 (46)
Prepregnancy BMI 25–29.9	109 (31)
Prepregnancy BMI >30	77 (23)
Gestational weight gain, kg	12.7 \pm 0.34
Gestational weight gain	
Below/within recommendations	198 (57)
Exceeds recommendations	151 (43)
Mode of delivery	
Vaginal	281 (81)
Caesarean section	68 (19)
Duration of full breastfeeding	
1 mo	25 (7)
3 mo	64 (18)
6 mo	260 (74)
Infant gestational age at birth, wk	39.8 \pm 0.06
Infant sex	
Male	176 (50)
Female	173 (50)
Infant percent body fat	34.1 \pm 0.19

¹Values are mean \pm SE or frequency (%).

vaginally. Gestational weight gain exceeded the IOM recommendations for 43% of the participants. Most (74%) of infants were fully breastfed until 6 mo of age.

Maternal dietary characteristics

In general, mothers had somewhat higher-quality diets, with a mean Healthy Eating Index–2015 score of 66, compared with the typical American score of 59 from 2013–2014 (Table 2) (32). Most women exceeded recommendations for total fat or saturated fat. Only 3% of women met recommendations for fiber, whereas most women (61%) met added sugar recommendations.

Maternal dietary components and infant adiposity and growth

In covariate-adjusted linear regression models, maternal total fat intake (β : 0.84; $P = 0.04$) and saturated fat intake (β : 0.96; $P = 0.01$) had the strongest associations with infant %BF at 6 mo of age, with approximately a 1% increase in %BF per

TABLE 2 Maternal diet characteristics: mean daily intake and adherence to recommendations for fat, fiber, and added sugar ($n = 349$)¹

Diet variable	Value
HEI-2015 score	66.2 ± 0.42
Energy intake, kcal/d	1837 ± 27.2
Total fat intake, g/d	78.7 ± 1.38
Unsaturated fat intake	46.9 ± 0.89
Saturated fat intake	25.2 ± 0.45
Fiber intake, g/d	18.0 ± 0.35
Added sugar intake, g/d	44.9 ± 1.19
Fat recommendations	
≤35% kcal (met)	89 (26)
>35% kcal (not met)	260 (74)
Saturated fat recommendations	
<10% kcal (met)	10 (3)
≥10% kcal (not met)	339 (97)
Fiber recommendations	
≥14 g/1000 kcal (met)	11 (3)
<14 g/1000 kcal (not met)	338 (97)
Added sugar recommendations	
<10% kcal (met)	213 (61)
≥10% kcal (not met)	136 (39)

¹Values are mean ± SE or frequency (%). HEI-2015; Healthy Eating Index–2015.

SD for each of these diet components (Table 3). Raw maternal dietary intake of unsaturated fat, fiber, and added sugars (grams per day) was not associated with infant adiposity. Regarding diet recommendations, infants of mothers who exceeded added sugar recommendations had approximately 1% greater %BF compared with infants of mothers who met recommendations (β : 0.75; $P = 0.05$) (Table 4). In terms of the anthropometric outcomes examined, for each SD of added sugar intake, there was approximately a 0.2 SD greater infant WLZ (β : 0.16; $P = 0.02$) (Table 5). Maternal dietary intake of fat, saturated fat, unsaturated fat, and fiber were not associated with WLZ, LAZ, or Δ WAZ at the $P < 0.05$ level, and no appreciable differences in Δ WAZ, LAZ, or WLZ were noted for infants of women who exceeded dietary recommendations for fat or added sugar compared with those who met recommendations (Supplemental Table 1).

Secondary analyses and sensitivity analyses

Previously, we showed that infant %BF is strongly influenced by full breastfeeding status (21), and so we desired to contextualize the magnitude of maternal diet–infant adiposity relations in comparison to this effect and known sexual dimorphism in body composition. Infants who were fully breastfed to 1 mo had higher %BF compared with infants receiving only formula for the same time period. Thus, in the current study, we also compared effect sizes for full breastfeeding status (1, 3, or 6 mo) with the effect of maternal dietary intake of fat and saturated fat in adjusted models (Supplemental Table 2). Although dietary fat intake (g/d) was associated with nearly a 1% increase in %BF per SD (SD = 25.6 g), cessation of full breastfeeding after only 1 mo was associated with a 2% decrease in %BF, and infant sex (female) was associated with 1.8% greater %BF. Similarly, saturated fat was associated with a 1% increase in %BF per SD (SD = 8.3 g), whereas cessation of full breastfeeding after 1 mo was associated with a 2% decrease in %BF, and sex (female) was associated with a 1.7% increase in %BF.

When examining associations between maternal dietary components and infant %BF at 6 mo adjusted for infant initiation of complementary foods, fat and saturated fat remained significantly associated with %BF (Supplemental Table 3). However, no difference in infant %BF was observed for mothers who met or exceeded recommendations for fat or added sugars (Supplemental Table 4).

When all 3 diet variables were simultaneously assessed in the same model, results were comparable to those when diet variables were tested in separate models. Mean maternal fat intake (g/d) remained independently associated with infant %BF (β : 0.96; $P = 0.03$), and mean sugar intake was independently associated with infant WLZ at 6 mo (β : 0.18; $P = 0.02$).

In sensitivity analyses, results were comparable for %BF and added sugar recommendations and WLZ and added sugar intake (g/d) when adjusted models were rerun in only infants who were fully breastfed to 6 mo of age (Supplemental Table 5). However, estimates for %BF and fat and saturated fat were diminished (β : 0.47 and β : 0.61, respectively) compared with those from adjusted models run on the full data set.

Discussion

We explored the association between maternal dietary components and infant growth and adiposity at 6 mo of age in a prospective cohort of predominantly breastfeeding infants. Our results reveal that higher intakes of total dietary fat and saturated fat were associated with increased infant %BF at 6 mo. Similarly, infants of mothers who exceeded recommendations for added sugar intake had higher %BF than infants of mothers who met recommendations. Added sugar intake was also associated with higher infant WLZ at 6 mo. To our knowledge, maternal adherence to current recommendations on these diet components and related infant growth and adiposity outcomes have not been examined previously in the literature. Some researchers have moved away from studying individual dietary components and have instead focused on dietary patterns of intake because one's overall diet may be a better indicator of disease risk than individual nutrient intake (33). However, recommendations for individual nutrients remain part of the DGA, and it is important to characterize growth and adiposity outcomes for infants of mothers who meet or do not meet these recommendations.

A number of studies have examined maternal dietary fat intake and neonatal size and body composition at birth. In the Healthy Start Study, Shapiro et al. (19) found that a high-fat maternal diet, defined as ≥30% total calories from fat and ≥12% of calories from saturated fat, was independently associated with infant %BF (β : 0.8; $P < 0.01$) and fat mass (β : 32.4; $P < 0.01$) assessed via air displacement plethysmography within 72 h of birth. Also using data from the Healthy Start Study, Crume et al. (34) found that maternal intake of total fat (β : 4.2 g/100 kcal; $P = 0.03$) and saturated fat (β : 11.1 g/100 kcal; $P = 0.03$) during pregnancy was associated with infant fat mass at birth.

As far as later infancy outcomes are concerned, Brei et al. (35) examined maternal dietary intake in early (week 15) compared with late (week 32) gestation and infant growth and body composition at 6 wk, 1 y, 3 y, and 5 y using predictive skinfold regression equations and ultrasonography. They found that in later pregnancy, 100-kcal increases in total fat and saturated fat were associated with a significant decrease in subcutaneous fat area at 1 y, whereas 20 kcal fiber was associated with an increase

TABLE 3 Maternal dietary fat (total and saturated) is associated with infant %BF at 6 mo of age ($n = 349$)¹

Diet variable (per SD)	%BF at 6 mo			
	Crude		Adjusted ²	
	Estimate \pm SE	P value	Estimate \pm SE	P value
Fat, g/d	0.50 \pm 0.20	0.013	0.84 \pm 0.40	0.04
Saturated fat, g/d	0.62 \pm 0.19	0.001	0.96 \pm 0.37	0.01
Unsaturated fat, g/d	0.40 \pm 0.20	0.049	0.47 \pm 0.35	0.18
Fiber, g/d	0.09 \pm 0.20	0.650	−0.54 \pm 0.31	0.08
Added sugars, g/d	0.40 \pm 0.19	0.041	0.24 \pm 0.22	0.27

¹Values expressed per SD as estimate \pm SE. %BF, percent body fat.

²Model adjusted for center (Minnesota or Oklahoma), maternal age, race, income, full breastfeeding, prepregnancy BMI, parity, mean daily energy intake, gestational weight gain recommendations met, and infant sex and gestational age at birth.

in subcutaneous fat area at 1 y of age. Lack of agreement with our study findings may be due to differences in time points for both maternal diet assessment and infant measurements, as well as differences in body composition methods used. In addition, the duration of full breastfeeding for this cohort was not reported.

We found that women who consumed excess added sugar had infants with higher %BF and that overall maternal added sugar intake (g/d) was associated with greater WLZ at 6 mo of age. Although few studies have examined associations between maternal intake of added sugars and infant outcomes, Chen et al. (36) found that maternal added sugar intake during pregnancy was associated with higher peak BMI in infancy and higher BMI in early childhood. Similarly, Jen et al. (37) found that maternal intake of sugar-containing beverages during pregnancy was positively associated with childhood BMI at ≤ 6 y of age, although the effect was small [per serving of sugar-containing beverage/day: 0.04 SD score (SDS); 95% CI: 0.00, 0.07 SDS]. Thus, it is plausible that the associations between maternal intake of added sugars during pregnancy and growth and adiposity in early infancy may carry into later childhood.

Our finding that greater maternal fat intake was associated with higher infant %BF aligns with previous research revealing that maternal dietary intake of fat affects the fatty acid composition of human milk. Innis (38) provides an excellent summary of the research in a 2014 review. Fatty acids are supplied through synthesis by the mammary gland or from maternal plasma; thus, their availability is affected by maternal nutrition status. Insull et al. (39) reported this relation as early as 1958, when they found that the fatty acid content of human milk closely reflected dietary fat intake when mothers were fed lard or corn oil as the primary source of fat.

Conversely, Bravi et al. (40) conducted a systematic review examining evidence for the influence of maternal diet on human milk composition in studies that quantified the associations directly in healthy mothers of term infants. From these studies, they were unable to find sufficient evidence to conclude that there was any relation between maternal diet and human milk composition. This was partly due to the very few studies that fulfilled their inclusion requirements, as many studies had not directly quantified nutrients of interest in both maternal diet and breast milk. In addition, they found that very few studies had uniform standard for conduct (varying exposures and outcomes, lack of control for potential confounders), making comparison difficult (40).

In our exploration of effect sizes, we noted the effects of full breastfeeding for 1 mo or being female are equivalent to a ~ 2 SD increase in dietary fat. Differences in body composition between breastfed and formula-fed infants are well documented in the literature. Although breastfed infants initially have a higher %BF, their overall rate of growth and adiposity is eventually exceeded by that of formula-fed infants by a year of age (20). Some studies have linked early rapid growth to later elevations in BMI (41, 42). Sex differences in body composition have also been observed at birth and later infancy, with female infants having a greater %BF and less fat-free mass than males (43, 44). However, when controlling for breastfeeding exclusivity and sex in our adjusted models, dietary fat was still associated with nearly a 1% increase in %BF per SD. Thus, maternal dietary intake may influence %BF independent of full or mixed breastfeeding status and sex of the infant, although the effect is small, and the overall impact of infant adiposity at this time point on an infant's later health is unknown. We found that effect estimates were attenuated but still significant for fat and saturated fat when models were restricted to infants fully

TABLE 4 Maternal excess added sugar intake is associated with infant %BF at 6 mo of age ($n = 349$)¹

Diet recommendation	%BF at 6 mo			
	Crude		Adjusted ²	
	Estimate \pm SE	P value	Estimate \pm SE	P value
Fat		0.07		0.12
$\leq 35\%$ kcal (met)	Reference		Reference	
$> 35\%$ kcal (not met)	0.80 \pm 0.44		0.67 \pm 0.44	
Added sugars		0.06		0.05
$< 10\%$ kcal (met)	Reference		Reference	
$\geq 10\%$ kcal (not met)	0.73 \pm 0.39		0.75 \pm 0.38	

¹Values are estimate \pm SE. %BF, percent body fat.

²Model adjusted for center (Minnesota or Oklahoma), maternal age, race, income, full breastfeeding, prepregnancy BMI, parity, mean daily energy intake, gestational weight gain recommendations met, infant sex, and gestational age at birth.

TABLE 5 Maternal intake of added sugars is associated with infant WLZ at 6 mo of age ($n = 349$)¹

Diet variable, g/d	Crude		Adjusted	
	Estimate \pm SE	P value	Estimate \pm SE	P value
Change in WAZ (1–6 mo) ²				
Total fat	−0.012 \pm 0.05	0.80	0.005 \pm 0.10	0.96
Saturated fat	−0.004 \pm 0.05	0.93	−0.024 \pm 0.09	0.79
Unsaturated fat	−0.017 \pm 0.05	0.74	0.009 \pm 0.09	0.92
Fiber	−0.028 \pm 0.05	0.58	−0.007 \pm 0.08	0.93
Added sugars	0.046 \pm 0.05	0.34	0.036 \pm 0.06	0.53
LAZ 6 mo ³				
Total fat	0.11 \pm 0.06	0.08	0.002 \pm 0.13	0.99
Saturated fat	0.10 \pm 0.06	0.14	−0.080 \pm 0.12	0.50
Unsaturated fat	0.11 \pm 0.06	0.09	0.038 \pm 0.11	0.73
Fiber	0.14 \pm 0.07	0.03	0.074 \pm 0.10	0.46
Added sugars	0.03 \pm 0.06	0.66	−0.023 \pm 0.07	0.74
WLZ 6 mo ⁴				
Total fat	0.04 \pm 0.06	0.51	0.042 \pm 0.13	0.75
Saturated fat	0.08 \pm 0.06	0.17	0.166 \pm 0.12	0.15
Unsaturated fat	0.01 \pm 0.06	0.82	−0.038 \pm 0.11	0.73
Fiber	−0.01 \pm 0.06	0.87	−0.071 \pm 0.10	0.47
Added sugars	0.13 \pm 0.06	0.02	0.161 \pm 0.07	0.02

¹Values expressed per SD as estimate \pm SE. LAZ, length-for-age z score; WAZ, weight-for-age z score; WLZ, weight-for-length z score.

²Model adjusted for center (Minnesota or Oklahoma), maternal age, race, full breastfeeding, prepregnancy BMI, parity, mean daily energy intake, gestational weight gain recommendations met + infant sex and gestational age at birth.

³Model adjusted for previously listed variables + length-for-age z score at birth.

⁴Model adjusted for model 1 variables + weight-for-length z score at birth.

breastfed to 6 mo, indicating that maternal diet is still associated with and may be important for growth outcomes in infants not fully breastfeeding.

Although the observed associations of maternal dietary components and infant adiposity and growth were not large in magnitude in this predominantly breastfeeding cohort of women with generally high diet quality, these dietary components have been linked to other maternal and infant outcomes, and adherence should still be prioritized. Very few women in our study met recommendations for fiber, but consuming adequate fiber is beneficial to prevent constipation, hemorrhoids, and diverticulitis in pregnant women, who are at higher risk for these conditions (45). In addition, maternal intake of added sugar has been linked with adverse neurodevelopment and behavioral outcomes in infants (46, 47). Following dietary recommendations for fat, the most calorically dense macronutrient, can assist mothers in achieving a balanced diet and staying within IOM guidelines for GWG, potentially leading to lower risk for gestational diabetes and infants who are large for gestational age (48).

Our study has numerous strengths, including its prospective cohort design and examination of detailed infant adiposity using DXA, a validated tool for assessment of infant body composition. In addition, we were able to adjust for numerous potential confounders such as maternal demographics, BMI, GWG, and other characteristics. Finally, we provided an examination of growth and adiposity outcomes for infants of mothers who did not meet dietary recommendations for fat and added sugar, filling a gap in the currently available literature.

Despite these strengths, our study has limitations that may have affected our results. Most study participants were highly educated, middle- to upper-class non-Hispanic white women, and 74% breastfed until 6 mo of age. Thus, our results are not generalizable to the entire population in the United States, where 25% of infants are fully breastfeeding at 6 mo of age (49). We

used the DHQ II, an FFQ to assess maternal dietary intake, and participants may have misreported their intake of fat, saturated fat, and added sugars, leading to regression dilution or lower observed effects than those we might have observed with a more precise and objective measure of true maternal dietary intake (50). However, repeated diet assessments showed moderate to strong reliability, and by averaging maternal dietary data across time points, we were able to minimize variability in the data and provide an estimate of diet effects on infant growth during a defined window of time (third trimester of pregnancy through 3 mo postpartum). In addition, our anthropometric and adiposity measurements did not extend until infants were 1 y of age. Thus, we are not able to provide needed information on changes in body composition in relation to maternal diet and feeding mode at this or later time points. As our study was an observational study, we are not able to draw conclusions on causal relations between exposures of interest and outcomes.

Conclusions

In a prospective cohort study of predominantly breastfeeding women, we found that mean maternal dietary fat and added sugar intake during the third trimester of pregnancy and 1 and 3 mo postpartum was positively associated with infant %BF and WLZ at 6 mo, respectively. Although the effects of dietary intake were not of large magnitude, our study confirms a small number of earlier studies on infants at birth suggesting that maternal diet plays a role in infant growth outcomes. Furthermore, adhering to dietary guidelines is important for other maternal and infant outcomes and should be supported. Further research is needed to determine the impact of maternal diet variation on human milk composition, including human milk oligosaccharides, fatty acid profiles, lipids, milk bioactive hormones, and other features, so as to better understand the

relevance of maternal diet for optimal infant nutrition and growth in the first 1000 d of life.

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The authors' contributions were as follows—EWD and DAF: designed research; LF and KD: conducted research; EWD and DJ: designed statistical analysis; EMN: analyzed data with assistance from KEJ, drafted the paper, and had primary responsibility for final content; DJ, KEJ, EOK, BG, LH, DAF, and EWD: provided critical revisions for the paper; and all authors: read and approved the final manuscript.

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